Effect of Packings on Gas Distribution and Holdup in a Bubble Column

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ABSTRACT

Random or structured packing is always included in the chemical reaction columns to increase the contact area between phases and thus improve reaction efficiency. Knowledge of how packing types and sizes affect the gas distribution and overall gas holdup is critical parameters for the effective design and operation of industrial process, such as absorption, stripping and distillation. In this work, the gas distribution and overall gas holdup are measured in-situ using Electrical Resistance Tomography (ERT). The effect of packing on these parameters is studied. Experimental results show that the presence of packing considerably changes the gas distribution and holdup. Additionally, the simulation and experiment results show that ERT is able to quantitatively determine the volume fraction with up to 5.2% relative error against the true value. All of these facts suggest that ERT is an efficient quantitative imaging tool for the real-time measurement of complex two-phase flows.

Keywords Electrical resistance tomography (ERT), Gas-liquid two-phase flow, Gas distribution and holdup, Packed Column

1 INTRODUCTION

In the gas-liquid two-phase flows, the packing is always added in the reaction column, because the packing can prolong gas or liquid to pass through the reaction column and improve contact area between the gas and liquid phases of the mass transfer process. The existence of the packing makes the flow visualisation even more difficult. Gamma-ray tomography (Fourati 2012) is one of options, particularly for the situation requiring high spatial resolution. Electrical Resistance Tomography (ERT) could be considered a non-intrusive, safer, and lower cost alternative to gamma ray tomography which could be used in process industries to extract gas holdup and velocity and visualize information flow distribution in a column. Other researchers have started to apply ERT for monitoring (Hurry 2007; Eda 2012; Wei 2015). The study introduced in this paper is to use ERT to measure gas holdup inside a bubble reactor column with different type of packing. The dependence of gas distribution and holdup on packing is investigated and discussed.

2 PRINCIPLE AND METHOD

In ERT measurement, the excitation source is applied between an adjacent pair of peripheral electrodes, while the induced potential difference is simultaneously acquired at the other electrode pairs. Excitation and acquisition are continuously and rapidly repeated until all the possible electrode combinations are measured. After all the independent potential differences are collected, a cross-sectional image showing the relative conductivity contrast between homogenous continuous phase and heterogeneous mixture is reconstructed by solving an inverse problem. More importantly, the local holdup of the dispersed phase can be derived from the information of conductivity using the method of modified sensitivity back projection (Jia 2014). Beside the local holdup, the velocity of dispersed phase can be obtained from the data of multi-layer ERT system using cross-correlation method. Compared with two-phase flow in a hollow pipe, using ERT to measure gas-liquid flow in a packed reaction column is a relatively new application. The existence of the packing material will significantly change the path of fluids and the packing will also bring difficulties for ERT measurement.

Figure 1 (a) shows the procedure of measuring gas holdup in the hollow pipe. The reference is taken when the pipe is filled up with water. If the chemical reaction has to involve packing, as illustrated in Figure 1 (b), the reference could be taken from water plus packing before gas is introduced. However, it is very difficult to draw a geometry representing realistic water plus packing then compute its sensitivity matrix in the FEM software. If the conventional sensitivity matrix as in Figure 1 (a) is used instead for simplicity, a large error must be caused for image reconstruction and gas holdup calculation. Alternatively, gas holdup can be obtained via a few steps demonstrated in Figure 1 (c). Firstly the reference is taken from water only. Then the packing is added into the pipe, its volume fraction of packing is found. After Gas is introduced into the pipe, the total volume fraction of packing and gas is calculated by ERT. In fact, if the continuous phase is conductive, ERT is able to handle the full volume fraction range in two-phase flow measurement (Jia 2014). At last the volume fraction of gas is the difference between the total volume fraction and the volume fraction of packing in subtraction. In the following sections, the accuracy of this procedure for different packing is presented.

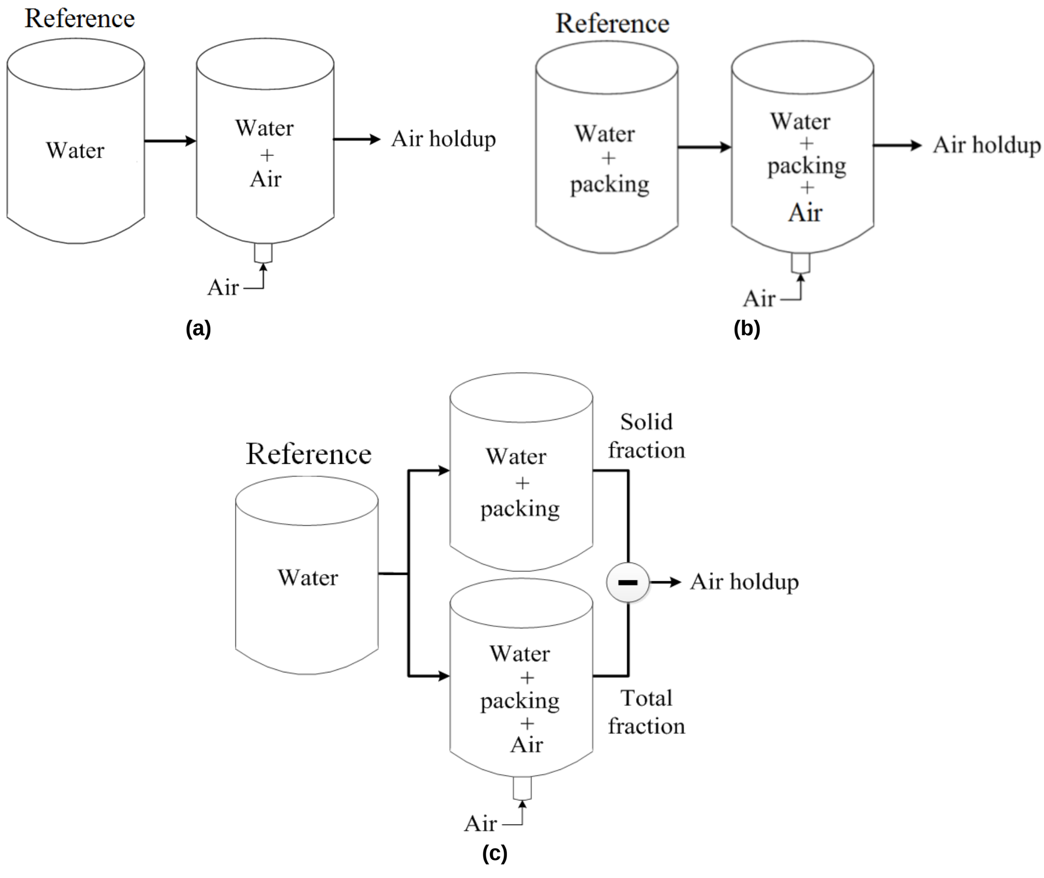
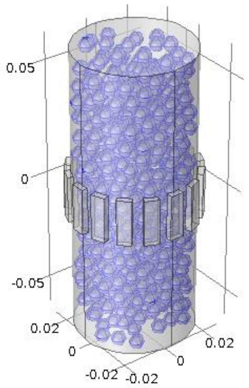


Figure 1. Gas holdup Measurement procedures of ERT (a) procedure for hollow pipe; (b) procedure 1 for packed column; (c) procedure 2 for packed column.

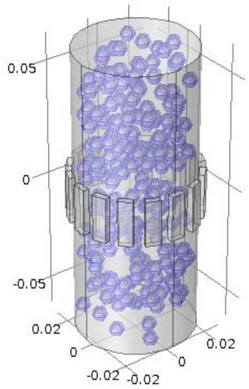
3 SIMULATION RESULTS

To validate the accuracy for ERT's holdup measurement, three 3D ERT simulations were conducted by combining COMSOL Multiphysics 5.2 with MATLAB. The first and second simulation calculated the volume fraction of glass beads and compared with the true value. The third one calculated the air holdup in a glass beads packing column and also compared with true value. In the first simulation, a 3D cylindrical model was built. The cylindrical column had 50 mm internal diameter and 125 mm height. 16 stainless steel rectangular electrodes with 6 mm width and 20 mm height. These dimensions were the same with these of the experimental rig described in the next section.

Represented by blue spheres in Fig.3, 500 glass beads with 6 mm diameter were randomly packed in the column. The conductivity of glass beads was set to 10^{-10} mS/cm and the remaining space inside the column was set to 10 mS/cm. The first ERT procedure in section 2 was applied to this simulation phantom to obtain the volume fraction of glass beads. Meanwhile, the volume fraction of glass beads in the column was determined by their total volume against the volume of column. Since the number and the diameter of sphere are known, the volume fraction is regarded as a true value. In the second simulation, 200 glass beads were randomly distributed. The volume fractions computed from two approaches are compared in Table 1. The relative errors are around 5%.



(a)



(b)

Figure 2. 3D model of ERT phantom and glass beads with 6mm diameter (a) 500 glass beads; (b) 200 glass beads.

Table 1. Volume fractions of glass beads with 6mm diamter.

Number of glass beads	500	200
True volume fraction	0.230	0.092
ERT's result	0.242	0.088
Relative error	5.2 %	4.3%

In the third simulation, 500 spheres with 6 mm diameter were distributed inside the column, however the half of these spheres were randomly classified as glass beads (represented by blue spheres in Figure 3) and as air for another half (represented by grey spheres in Figure 3). The conductivities of blue and grey spheres were set to 1×10^{-10} and 5×10^{-14} mS/cm, respectively. It can be shown from Table 2 that the total volume fraction of the blue and grey spheres can be obtained from simulated ERT data. Subtracting the volume fraction of blue spheres 0.115 from the total volume fraction of all the blue and grey spheres yields the volume fraction of grey spheres (on the fourth row in Table 2) while the true value of the volume fraction of all grey spheres is calculated to be 0.115. The relative errors between true value and ERT's resulte is 2.6%. These simulation results above demonstrates that ERT is a very accurate tool for finding the air holdup in the packing column.

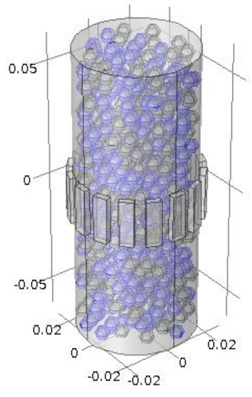


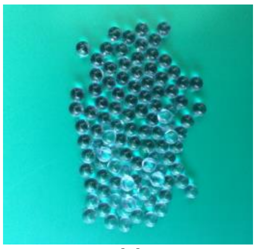
Figure 3. 3D model of ERT system with blue and grey shperes with 6mm diameter.

Table 2. Volume fraction of grey spheres with 6mm diameter.

Background conductivity (mS/cm)	10
True volume fraction of grey spheres	0.115
ERT's result for all spheres f_{all}	0.236
ERT's results for grey spheres $f_{grey} = f_{all} - 0.115$	0.118
Relative error	2.6%

4 EXPERIMENT SETUP

The packing materials are shown in Figure 4. The diameter of glass beads is 6mm. Plastic Pall rings are widely used in absorption, scrubbing, and stripping services. Relatively high liquid hold-up allows good absorption efficiency with slow chemical reaction. These packing materials are randomly heaped in the bubble column as shown in Figure 5. The column is made from the transparent acrylic resin with 50 mm internal diameter and 250 mm height. The middle of the column was surrounded by a plane of ERT sensor which was composed of 16 electrodes mounted into the inner walls of the column in a non-intrusive fashion. The electrodes are made of stainless steel with the rectangular contact areas of 6 mm width and 20 mm height. In the bubble column, aqueous NaCl salt water solutions with 5.04 mS/cm conductivity is used as a continuous liquid phase and air was used as a gas phase. Air was continuously injected through a small nozzle with 4.63 mm diameter at the centre of the column bottom and into the interior of the column. In the experiment, the air flow rate was set to 0.52 L/min 1.09 L/min and 1.60 L/min. The gas volumetric flow rate is controlled by an XFM digital mass flow meter of Aalborg Instruments & Controls, Inc. At the beginning, besides gas-liquid flow, the bubble column was not filled with any packing. The gas distribution and holdup was measured as a benchmark. Afterwards, glass beads and plastic pall rings were added separately for comparison. The gas distributions and its overall holdups in the packing free and the packed column were calculated using the v5r Electrical Resistance Tomography System from Industrial Tomography Systems plc. In each experiment, the system collected 10000 frames of images at a rate of 125 frames/s, which is the slowest rate for highest measurement accuracy.



(a)

(b)

Figure 4. Packing materials (a) glass beads; (b) plastic pall rings.

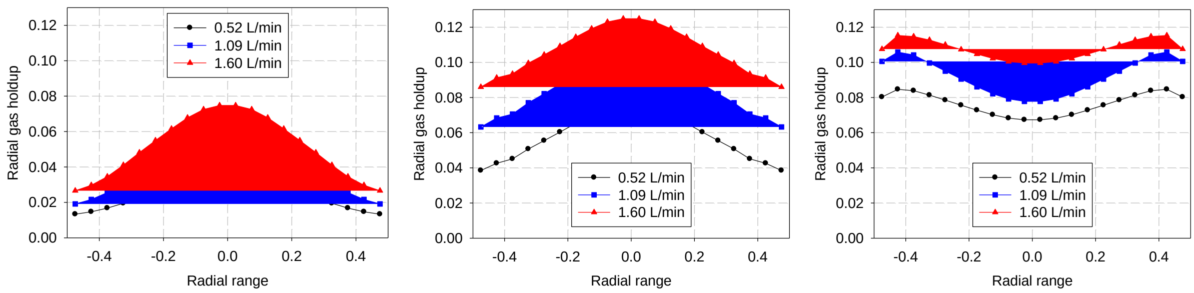
(a) (b)

Figure 5. Packed bubble column (a) glass beads packing; (b) plastic pall rings packing.

5 EXPERIMENT RESULTS AND DISCUSSION

The first ERT measurement procedure in Section 2 was used for the packing free flow and the third measurement procedure was used for the flow with packing. The local gas holdups in the same concentric ring zone are averaged and plotted as radial gas holdup profile. In the packing free situation, the air radial holdup distributions have similar bell-shaped profiles in Figure 6 (a), which illustrates that the air has higher holdup at the centre of the column and lower holdups towards to the pipe wall. For the column with the plastic pall rings packing, the profiles in Figure 6 (b) maintain the similar shape, but the gas holdups are shifted up. Because the packing resists the motion of bubbles, they have devious pathways from the bottom to the top of the column and remain longer time in the column. The instantaneous gas holdup is larger than without packing. In contrast, the glass beads packing clearly alters the radial gas holdup distribution as shown in Figure 6 (c). The gas holdups in the centre is even smaller than those around the pipe wall. The glass beads are packed much denser than the plastic pall rings, which gives bubbles less room to pass through.

In addition to the radial gas holdup distribution, the overall air holdup is also an important process indicator. The corresponding experimental results are shown in Figure 7. It can be seen that the overall gas holdup has a strong linear relationship with the gas volumetric flow rate in both the packing free column and packed columns. The overall magnitude of the radial air holdup increases uniformly with the increase of air volumetric rate. The upward shift of the overall gas holdup is attributed to the fact that the length of gas pathway is prolonged due to the packing. These results are also found by Niranjan [18] who determined the gas phase holdup in a packed bubble column by measuring the dispersion height for a given superficial gas velocity and the height of a clear liquid after the gas flow had been stopped.



(a) (b) (c)

Figure 6. Radial gas holdup at different packings: (a) packing free; (b) plastic pall rings; (c) glass beads.

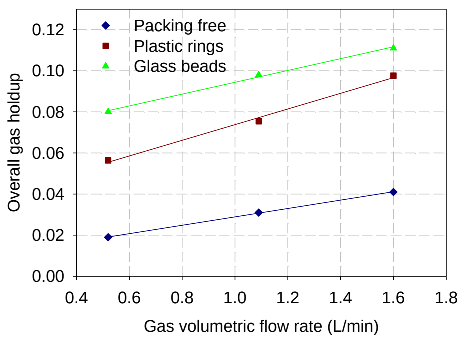


Figure 7. Gas overall holdup at different gas flow rate and packing.

6 CONCLUSION

The gas distribution and holdup in packing free and packed bubble column is measured and compared using Electrical Resistance Tomography (ERT) in this paper. The measurement procedures for different bubble column structures are discussed. The 3D column with ERT sensor is simulated in FEM software to verify the accuracy of ERT measurement. Two type of packings are tested in the experiment and benchmarked by the packing free column. The ERT experiment results demonstrated the effect of packings on gas distribution and holdup. The dense glass beads prolong the gas bubble more than plastic pall rings, alter the gas distribution and increase the overall gas holdup. Further work is planned to study counter-current gas-liquid flow with structured packing in order to understand more about CO_2 absorption process.

REFERENCES

EDA, T., SAPKOTA, A. AND TAKEI, M., (2012), Investigation of liquid dispersion in the packed-bed by electrical resistance tomography, *20th International Conference on Nuclear Engineering collocated with the ASME 2012 Power Conference*, 30 July-3 August 2012, California, USA.

FOURATI, M., ROIG, V. and RAYNAL, L., (2012), Experimental study of liquid spreading in structured packings, *Chemical Engineering Science*, 80, pp. 1-15.

HURRY, R., WANG, M., WILLIAMS, R. A. and CROSS, C., (2007), An Electrical Impedance Sensing System for Monitoring Hydraulic Flow Transport in Heap Leach Test Columns, *5th World Congress on Industrial Process Tomography*, 3-6 September 2007, Bergen, Norway.

JIA, J., WANG, M. and FARAJ, Y., (2014), Evaluation of EIT systems and algorithms for handling full void fraction range in two-phase flow measurement, *Measurement Science and Technology*, 26, pp. 1-7.

NIRANJAN, K. and PANGARKAR, V. G., (1984), Gas Holdup and Mixing Characteristics of Packed Bubble Columns, *The Chemical Engineering Journal*, 29, pp. 101-111.

WEI, K., QIU, C., LIANG, S., SOLEIMANI, M., AND PRIMROSE, K., (2015), Using 3D Electrical Resistance Tomography for Packed Bed Column Monitoring, *7th International Symposium on Process Tomography*, 1-3 September 2015, Dresden, Germany.